Type of Report: Semi-Annual, July-December 1993 Alfredo R. Huete, University of Arizona
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TASK OBJECTIVES

The objective of the second half of this years' effort was to complete the analysis of the basic structure for the vegetation index equation. The skeletal framework for the equation follows the normalized difference vegetation index (NDVI) with two modifications designed to reduce NDVI sensitivity to atmospheric and canopy background variations. The improved NDVI equation follows a systems approach and utilizes feedback loops for noise removal and a forward compensation loop to maintain the vegetation signal. Another objective was to set the criteria for vegetation index evaluation and validation, including error, uncertainty, and accuracy analyses schemes applicable to global conditions. The validation effort includes a radiometric as well as biophysical component and utilizes three types of data sets which include: (1) simulated data sets using canopy and atmospheric radiant transfer code; (2) field-based (ground and low-altitude) observational data sets; and (3) high-altitude, aircraft and satellite data sets. Each component includes uniform to complex canopies over a variety of land cover types. Much of the preliminary results were presented= in the first version of the Algorithm Theoretical Basis Document (ATBD). Additional objectives include further development of the MODIS test site effort for VI validation and refining the spatial and temporal compositing of the level 2 VI product into the level 3, gridded vegetation map, with primary attention given to the "view" angle problem of surface anisotropy.

WORK ACCOMPLISHED

1. Vegetation Index Equation

1.1. SARVI

A manuscript entitled "An error and sensitivity analyses of the atmospheric- and soil-correcting variants of the NDVI for MODIS-EOS, by Huete, A. and Liu, H., was submitted to IEEE Trans. Geosc. and Remote Sensing in September, 1993.

This study involved both canopy radiative transfer models as well as field observational data. It was found that both the soil-correcting and atmospheric- resistant variants of the NDVI significantly improved upon the NDVI.= =20
The abstract follows:

ABSTRACT: Several soil- and atmospheric correcting variants of the normalized difference vegetation index (NDVI) have been proposed to improve its accuracy in estimating biophysical plant parameters. In this study, a sensitivity analyses, utilizing simulated and observational data, was conducted on the NDVI and improved variants by analyzing the atmospheric-and soil- perturbed responses of each VI as a continuous function of two vegetation parameters (LAI and %green cover). Absolute and percent relative errors, and vegetation equivalent noises (VEN) were calculated for soil and atmospheric influences, separately and combined. The NDVI variants included the soil-adjusted vegetation index (SAVI), the atmospherically resistant vegetation index (ARVI), the soil and atmospherically resistant vegetation index (SARVI), the modified SAVI (MSAVI), and modified SARVI (MSARVI). =20

Soil and atmospheric error were of similar magnitudes, but varied with the vegetation index. All new variants outperformed the NDVI. It was found that the atmospherically resistant versions minimized atmospheric noise, but enhanced soil noise while the soil adjusted variants minimized soil noise, but remained sensitive to the atmosphere. The SARVI, which had both a soil and atmosphere calibration term, performed the best with an absolute error of +/- 0.06, relative error of 10%, and VEN of +/-0.33 LAI. By contrast, the NDVI had absolute and relative errors of 0.12, 20%, and 0.82 LAI, respectively. =20

The structure of the SARVI equation may be written as:

$$SARVI = [(\rho^*nir - \rho^*rb) / (\rho^*nir + \rho^*rb + L)] (1 + L),$$

$$\rho^*_{rb} = \rho^*_{r} - \gamma (\rho^*b - \rho^*r).$$

The 'L' term provides feedback for soil background noise removal and the g term in conjunction with the blue band minimizes atmospheric sources of noise attributed to varying aerosol contents. The SARVI thus requires correction (ρ^*) for atmospheric gases, namely Rayleigh scattering and ozone absorption. Although the SARVI greatly reduced soil and atmospheric influences, relative to the NDVI, they were not both reduced is a systematic, predictable manner. This is because the SARVI minimizes atmospheric and soil noise through independent means without considering combined or 'coupled', interactive effects of soil and atmosphere (see Figs. 1 & 2).

1.2. MNDVI

A systems based approach was then developed to further minimize noise in the NDVI by utilizing a feedback-based equation to minimize both independent and interactive atmospheric-soil background influences on the NDVI signal. The systems approach refines the soil- and atmospheric properties of the SARVI and improves considerably the performance of the VI. A paper entitled "A systems based modification of the NDVI to minimize soil and atmospheric noise" by Liu, H., and Huete, A. is in preparation for submission to IEEE Trans. Geosc. and Remote Sensing. The abstract follows:

ABSTRACT: The Normalized Difference Vegetation Index (NDVI) equation is an 'operator' with a simple, open loop structure. This renders the NDVI susceptible to large sources of error and uncertainty over variable atmospheric and soil background conditions, which is less than satisfactory in meeting the need for accurate, long term vegetation measurements for the Earth Observing System (EOS) program. In this study, a systems analyses approach is used to examine noise sources in existing VIs and to develop a stable, modified NDVI (MNDVI) equation through incorporation of atmospheric and soil noise feedback. The closed- loop version of the NDVI was constructed by adding: (1) a soil and atmospheric noise feedback loop, and (2) an atmospheric noise compensation forward loop. In field observational data and simulated data, the MNDVI was found to produce high quality, soil and atmosphere self-correcting output. The resulting % relative error and vegetation equivalent noise resulting from soil and atmospheric variations were six times less than encountered with the NDVI and 2.5 times less than with the Soil Adjusted and Atmospherically Resistant Vegetation Index (SARVI). Its combined soil and atmospheric noise was smaller than 4% for any complex soil and atmospheric situation.

The basic structure of the MNDVI equation is,

$$MNDVI =3D (NDVI / (1 + C_1H1)) (1 + C_2H_2),$$

where H_1 and H_2 provide soil and atmospheric feedback and signal compensation and C_1 and C_2 are the loadings, controlling the extent of correction necessary (Fig. 1). As with the SARVI, the MNDVI utilizes the blue band and requires a Rayleigh correction for optimum performance. The advantages of the new MNDVI are that it not only minimizes noise influences caused by soil and atmosphere, but is independent of aerosol corrections. Thus, whether an image is corrected for aerosols, partly corrected for aerosols, or not corrected at all for aerosols, is not important and does not affect the MNDVI and spatial and temporal intercomparisons of MNDVI values. This greatly reduces the dependence of the VI to atmospheric correction algorithms and the errors and uncertainties contained within these algorithms. The improvement in noise reduction is diagrammed in Fig. 2.

2. SCF activities:

2.1. Walnut Gulch, Thematic Mapper Data

Karim Batchily, Program Coordinator, continued to work on the 1992 Landsat TM Imagery acquired over the Walnut Gulch site from April through November, 1992. The objective of this study is to investigate the multitemporal behavior of all NDVI variant equations across the watershed from desert shrubland sites to shrub-grass mixed sites, grassland, and mesquite bosque. Preliminary results of this work were presented at the PECORA-12 Symposium on "Land Information from Space-based Systems" sponsored by the EROS Data Center on August 23-26, 1993, in Sioux Falls, South Dakota. Although the VIs were fairly well correlated to each other and to ground-measured LAI, there were sigificant differences among these indices relevant to vegetation seasonal dynamic studies. Temporal parameters such as 'length of the growing season', 'peak greenness', and 'onset of senescence' varied with the vegetation index utilized.

Seasonal contrasts, important for land cover classification schemes, also differed with the VI used. For example, the seasonal dynamics of the grassland site were most strongly observed with the ARVI while the dynamics of the perennial shrub areas were more strongly seen with the SAVI. The GEMI, on the other hand, showed very little seasonal contrast at all sites. Currently, the set of eight cloudless TM images are being spatially aggregated to approximate MODIS imagery.

In a separate study, Gerardo de Lira Reyes, Ph.D. student, is investigating the spatial and temporal patterns across the U.S. - Mexico border, where there are significant land use differences. Spatial and temporal variations across the border are being analyzed with reflectance data and thermal data. Vegetation indices (VIs) and brightness parameters are being computed to study land use differences and the resulting impact on vegetation differences, soil differences, and temporal, phenological variations. The thermal data, in conjunction with the vegetation index results are used to infer differences in moisture condition and stress throughout the wet and dry seasons. This will be accompanied by a ground-based campaign to analyze the soil and biophysical properties of the surface. Significant differences in biomass, cover, and dry/green biomass ratios were found with the Mexican side subjected to more intense grazing use, resulting in a lack of dry plant material, as= well as lower amount of green growth. The NDVI, however, is unable to discriminate vegetation differences across the border due to noise effects from differences in soil color and amount of litter present. Some of the newer VI variants appear more successful in discriminating vegetation differences.

2.2. Niger-HAPEX

Wim van Leeuwen, a Ph.D. candidate used the ground, air and satellite data from HAPEX-Niger to further vegetation work for MODIS. Some preliminary results of this work have been presented at two meetings: (1) the PECORA-12 Symposium on "Land Information from Space-based Systems" sponsored by EROS Data Center on August 23-26, 1993, in Sioux Falls, South Dakota; and (2) the American Geophysical Union (AGU) Fall Meeting (December 6-10, 1993) in San Francisco, California. At the PECORA-12 conference, the seasonality patterns of the various VIs were presented with ground- based and low-altitude aircraft radiometric measurements over the fallow bush/grassland, fallow grassland, millet, degraded bushland,

and tigerbush subsites. Additionally, the sensitivity of the various VIs to leaf area index (LAI), biomass, and intercepted photosynthetically active radiation (IPAR) were investigated. Temporal integration of the SAVI was well correlated with integration of these biophysical plant parameters. The slope of the integrated SAVI versus total biomass was different for each biome and was a measure of the growth efficiency for each site.

The work presented at the AGU meeting mainly concerned the use of vegetation indices as indicators of both state (LAI, biomass) and rate (IPAR, CO2) biophysical variables. More emphasis was placed in validating the functionality between VIs and biophysical parameters for purposes of primary production modeling. The results of this work show that growth efficiency differences based on IPAR and CO_2-flux were observed to be different for each biome.

Currently, Wim van Leeuwen is utilizing high resolution reflectance data of leaves (obtained with an integrating sphere at the Niger site) and soil (surface soil samples) as input into SAIL and Myneni canopy radiative transfer models. We are attempting to simulate some of the complex biomes of the Sahel at varying architectural arrangements, vegetation densities, and soil backgrounds. This simulation is to further study VI sensitivity to biophysical parameters as well as to further investigate the directional effects of surface anisotropy and atmosphere on the VI product.

2.3. Walnut Gulch, ASAS Data

Hui Qing Liu, Research Specialist, is working on the 1991 ASAS imagery over the Walnut Gulch Experimental Watershed, focusing on the directional (view angle) patterns from the different land cover types (grassland, riparian vegetation, mesquite bosque, and shrub sites) and how these impact on the vegetation index behavior. This becomes crucial in multitemporal compositing of level 2 imagery and in differentiating changes due to the vegetation from those attributed to viewing direction. The data consists of atmospherically corrected as well as unaltered data and the 29 bands have been reduced into the first four MODIS bands. The advantages and limitations of different compositing approaches and VIs are being compared. Thus far, the improved, self-correcting VI's appear to facilitate multiangular interpretations by minimizing the complex atmospheric-soil-view angle interactions. The maximum value compositing (MVC) technique is not sufficient due to lack of adjustment for directional effects. The use of bidirectional models or information about the surface appears to be necessary to maintain the performance and accuracy needs of the VI for global monitoring of vegetation activity. The ASAS data are also being used to test different mixture modeling schemes for land cover analysis and soil plant-litter component extraction.

2.4. AVHRR-Data Analyses

We have initiated an AVHRR-vegetation index analysis for two purposes: (1) in order to become more familiar with the temporal and spatial compositing approaches and the associated problems and limitations encountered in this process; and (2) to investigate further the "soil artifact" problem.

Qi Jiaguo, in his Ph.D. dissertation, looked at the various test data sets compiled by the EROS Data Center in order to investigate the compositing approach to AVHRR VI data. He presented his results at the PECORA-12 Symposium on "Land Information from Space-based Systems" sponsored by EROS Data Center on August 23- 26, 1993, in Sioux Falls, South Dakota. His results suggest that one may need geometric-optical canopy information of specific biomes to effectively composite VI data. This suggests a strong dependence of the VI product with the land cover product.

Soil color and brightness differences are believed to be responsible for the large Saharan desert "artifact" areas in AVHRR vegetation index imagery. This problem represents a lower boundary condition of vegetation detection, affecting locust monitoring in the Sahel, and detection of the 'onset of greenness' in vegetation index imagery. A critical analysis is being made as to the internal (soil properties) and external (view-sun geometry and atmosphere) conditions that are likely to result in high VI values over non-vegetated surfaces. Observational and simulated, bidirectional soil and litter reflectance data are being analyzed and compared with optical data from sparse shrub and grass canopies, with and without atmospheric simulations. A "soil color index" involving the use of a 'green' band is being developed to correct the vegetation indices. The method is being tested on Landsat Thematic Mapper data and ground-atmosphere simulated, MODIS data. In comparison to AVHRR- normalized difference vegetation index results, the soil color index appears to significantly reduce the soil artifact, noise problem and thus, improve upon the detection and monitoring of vegetation in arid regions. The ability to correct for the "soil artifact" problem establishes the lower limits of vegetation detection, which in turn, determine the lower limits of vegetation "change" detection as well.=20

A proposal was submitted to the International Arid Lands Consortium (IALC) to further investigate this problem from a different viewpoint. The principal investigator, Dr. Arnon Karnieli of the Remote Sensing Laboratory, Ben Gurion University of the Negev, Israel, has proposed that the soil artifacts are actually photosynthetic, microphytic plant outcrops. This lower form of non- vascular plants, consisting of mosses, lichens, algae, fungi, and bacteria, have their own unique spatial and temporal patterns, which may easily confuse the VI signal in arid and semiarid regions. If, in fact, the desert artifacts are microphytic signals, then these microphytes by themselves may be useful in monitoring "change" in climate over a 10 year period.

2.5. VI-APAR relationships

Jose Epiphanio, a postdoctorate scholar from INPE, Brazil, is working on a 1991 bidirectional reflectance data set from the Maricopa farm, in Arizona. The analysis involves a study of how directional effects on the VI affect the determination of APAR over alfalfa. The relationship between vegetation indices and APAR follows previously conducted research whereby sun angle has minimal affect on the VI-APAR relationship while view angle has considerable influence. LAI, on the other hand, is very sensitive to sun angle. This shows that not all biophysical parameters are related to each other with respect to the VI signal.

3. SEMINARS, VISITS, AND MEETINGS.

Presentation: "Variation of Vegetation Indices Derived from Multitemporal TM Images", A.K. Batchily, A.R. Huete, S. Moran and Liu, presented at the PECORA-12 Symposium on "Land Information from Space-based Systems", August 23-26, 1993, held in Sioux =46alls, South Dakota.

Presentation: "Evaluation of Vegetation Indices for Retrieval of Soil and Vegetation Parameters", W.J.D. van Leeuwen, A.R. Huete, presented at the PECORA-12 Symposium on "Land Information from Space-based Systems", August 23-26, 1993, held in Sioux Falls, South Dakota.

Presentation: "On Compositing of Multitemporal Data Sets", Qi, J., Huete, A.R., Hood, J., and Kerr, Y., presented at the PECORA-12 Symposium on "Land Information from Space-based Systems", August 23-26, 1993, held in Sioux Falls, South Dakota.

Presentation: "Biophysical Validation of Vegetation Indices at HAPEX-Sahel", W.J.D. van Leeuwen and A.R. Huete, presented at the American Geophysical Union (AGU) Fall Meeting, December 6-10, 1993, held in San Francisco, California.

Meeting: Attended the National Science Foundation's (NSF) "All Hands Meeting" in Estes Park, Colorado, September 18-22.

Abstracts:

The following abstracts have been submitted to the IGARSS'94 (International Geoscience and Remote Sensing Symposium) committee for presentation in Pasadena:

1. "A Soil Color Color Index to Adjust for Soil and Litter Noise in Vegetation Index Imagery of Arid Regions", A.R. Huete, H. Liu, G.R. de Lira, K. Batchily and R. Escadafal.

2. "Optical and Seasonal Variations Along the U.S. Mexico Border: an Analysis with Landsat TM Imagery", G.R. de Lira, K. Batchily, J. Hongtao and A.R. Huete.

3. "Biophysical Interpretation of Spectral Mixture Models Based on Radiative Transfer Models and Observational Data", W.J.D. van Leeuwen, A.R. Huete and C.L. Walthall.

4. "Influence of Sun-View Geometries on the Relationships among Vegetation Indices, LAI and Absorbed PAR", J.C.N. Epiphanio, A.R. Huete and H. Liu.

5. "A Systems Based Modification of the NDVI to Minimize Soil and Atmospheric Noise", H. Liu and A. Huete.

6. "Directional Vegetation Index Interactions in ASAS Imagery", A.R. Huete and H. Liu.

ANTICIPATED FUTURE ACTION

1. Use the Landsat TM scenes to simulate 250m, 500m, and 1km pixel sizes and analyze VI results at the different resolutions, including sub-pixel cloud behavior and effects on the VI.

2. Start processing the ASAS data collected over HAPEX-Niger to investigate directional effects on the VI over various land cover types.

3. Incorporate '6S' radiative code into the ASAS data set to further look at atmosphere-surface anisotropy on VI directional patterns.

4. Acquire China, 1km daily AVHRR data set and begin compositing approaches and alternatives with new indices. Perform preliminary land cover classifications with various VIs and incorporate the results into the China test site effort. Continue to pursue contacts with the Chinese Ecological Research Network (CERN) to develop MODIS test sites of sensitive areas.

5. Continue work on using the 3-dimensional Myneni plant radiative transfer model to simulate complex canopies for part of the VI biophysical validation.

6. Continue to work with Steve Running and the NSF-LTER scientists to incorporate the LTER sites into the VI validation effort.

7. Complete version 2 of the Vegetation Index ATBD.

8. Hold a special Vegetation Index Meeting at NASA/GSFC, Jan. 31-Feb. 2, 1994.

PUBLICATIONS

Huete, A.R., Justice, C.O., and Liu, H., "Development of vegetation and soil indices for MODIS-EOS" , Remote Sens. Environ. (in press).

Qi, J., Huete, A.R., Cabot, F., and Chehbouni, A., 1994, Bidirectional properties and utilizations of high resolution spectra from a semi- arid watershed, Water Resources Research (in press).

Huete, A.R., and Liu, H., 1994, An error and sensitivity analyses of the atmospheric- and soil-correcting variants of the NDVI for MODIS-EOS, submitted to IEEE Trans. Geosc. and Remote Sensing (Aug. 1993).

Running, S.W., Justice, C., Salomonson, V., Hall, D., Barker, J., Kaufman, Y., Strahler, A., Huete, A., Muller, J.P., Vanderbilt, V., Wan, Z.M., Teillet, P., and Carneggie, D., 1994, Terrestrial remote sensing science and algorithms planned for EOS/MODIS, Int. J. Remote Sensing (in press).

van Leeuwen, W.J.D., Huete, A.R., Duncan, J., and Franklin, J., 1993, Radiative transfer in shrub savannah sites in Niger -- preliminary results from HAPEX-II-Sahel: 3. Optical dynamics and vegetation index sensitivity to biomass and plant cover, Agric. and Forest Meteorology (in press).

Qi, J., Chehbouni, A., Huete, A.R., and Kerr, Y.H., 1993, A modified soil adjusted vegetation index, Remote Sens. Environ. (in press).

Franklin, J., Duncan, J., Li, X., Huete, A.R. and van Leeuwen, W.J.D., 1994, Radiative transfer in a shrub savannah -- preliminary results from HAPEX-II-Sahel: 2. Modelling surface reflectance and vegetation indices using a geometrical-optical approach, Agric. and Forest Meteorology (in press).

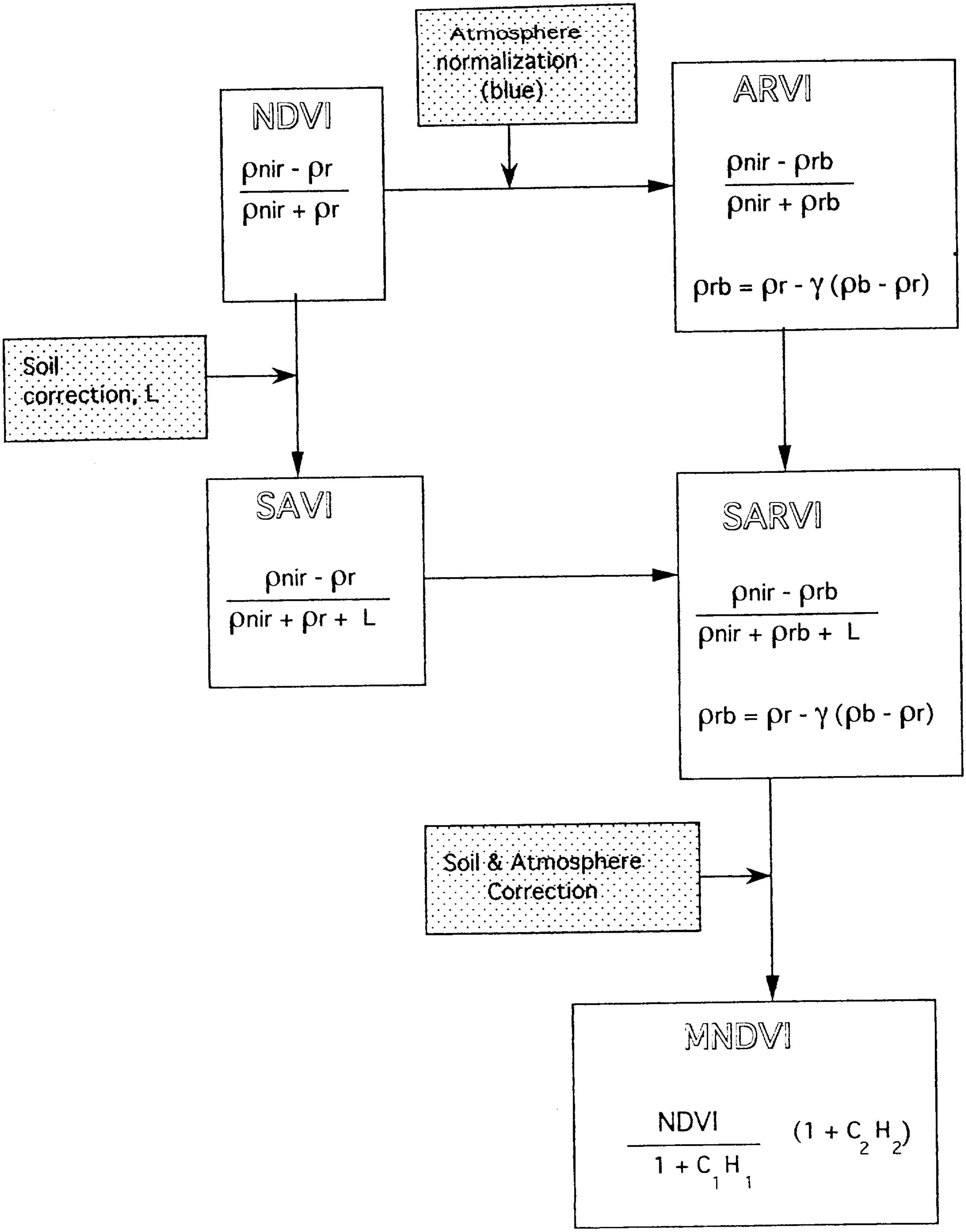
Atmosphere normalization (blue)
NDVI
$\frac{\rho nir - \rho r}{\rho nir + \rho r}$
ARVI
$\frac{\rho nir - \rho rb}{\rho nir + \rho rb}$
$\rho rb = \rho r - \gamma (\rho b - \rho r)$
Soil correction, L
SAVI
$\frac{\rho nir - \rho r}{\rho nir + \rho r + L}$
SARVI
$\frac{\rho nir - \rho rb}{\rho nir + \rho rb + L}$
$\rho rb = \rho r - \gamma (\rho b - \rho r)$
Soil & Atmosphere Correction
MNDVI
$\frac{NDVI}{1 + C_1 H_1} (1 + C_2 H_2)$

Figure 1

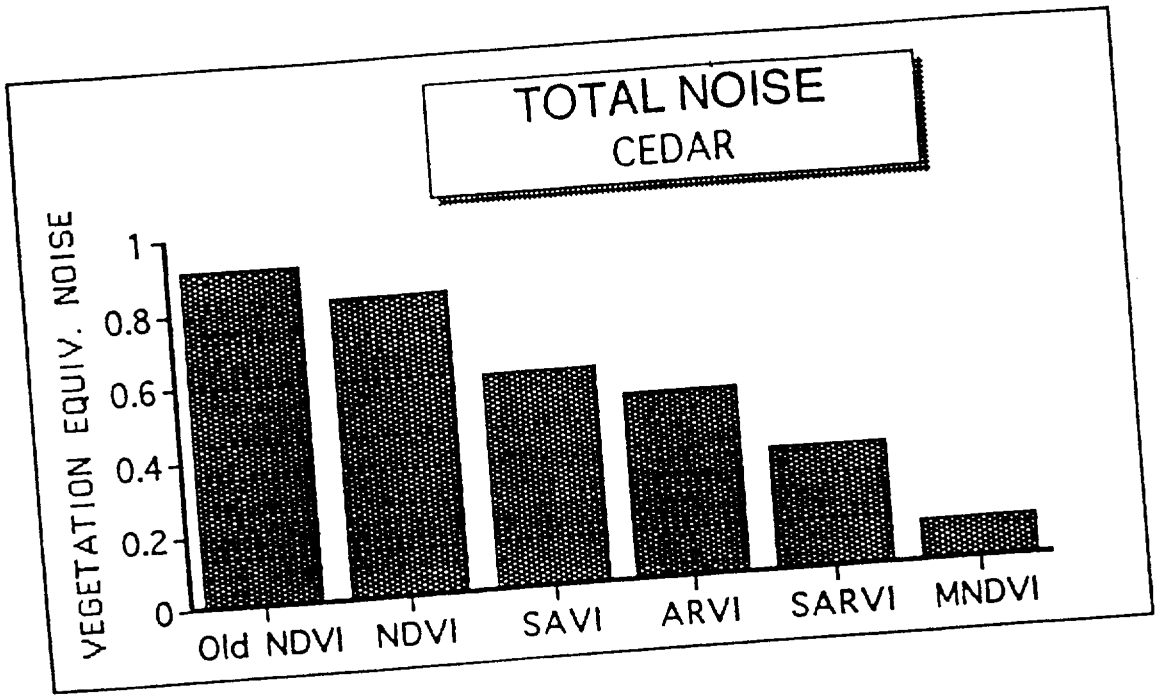

Figure 2. Comparisons of combined soil and atmospheric VI average noise (VEN) for the AVHRR-NDVI, MODIS NDVI, and MODIS NDVI variants using simulated cedar data.